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Ammonia Emissions from USA Broiler Chicken Barns Managed with New Bedding, Built-up Litter, or Acid-Treated Litter

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Abstract. *Poultry producers in the United States have attempted to maintain barn aerial ammonia (NH_3) levels below 25 ppm to improve air quality, and more recently to decrease aerial emissions to the atmosphere. Our objective was to investigate the influence of litter management strategies on NH_3 emissions from commercial broiler barns employing new bedding, acid-treated built-up litter (sodium bisulphate), or untreated built-up litter (normal practice). Nearly 400 barn-days of NH_3 emissions data were collected from 12 broiler barns on four farms monitored in 48-hour episodes over one year. On each study farm, the barns were paired for repetition of conditions. Emission was calculated as the product of gas concentration of the exhaust air and barn ventilation rate. Use of new bedding for every flock led to consistently lower NH_3 emission (averaging 0.35 g NH_3/(bird d)) at day 21 of the 42-day flock grow-outs, followed by flocks raised on the annual cleanout with new bedding (0.52 g NH_3/(bird d)). Built-up litter without any treatment had the highest emission (0.73 g NH_3/(bird d)), followed by the built-up litter with acid treatment (0.63 g NH_3/(bird d)). One study site was managed with two barns using litter treatment and two identical barns with untreated, built-up litter for a side-by-side comparison of results under field conditions. Ammonia emissions from treated built-up litter barns were similar to those from untreated built-up litter barns, however, the temporal pattern of emissions provided evidence that ammonia held in the acid-treated litter at the beginning of the flock was released during the latter period of the flock cycle.*

Keywords. *Ammonia control, Poultry, NH_3, Emission rate*

Introduction

A number of studies to characterize baseline U.S.A. ammonia emissions from broiler chicken facilities have been recently completed (Burns et al., 2003, 2007; Copeland, 2007; Gates et al., 2008; Lacey et al., 2003; Wheeler et al. 2006) and are being used by regulatory agencies and concerned citizens groups who are interested in regional and national air quality improvements.

Many instruments and techniques are available for measuring ammonia concentration (Ni and Heber, 2001). Ammonia monitoring instruments suffer from challenges of high cost for very accurate models and inconsistent accuracy and reliability for more affordable sensor technologies (Gates *et al*., 2005) unless the lower cost sensors are built into an instrumentation system that can accommodate their shortcomings (Xin et al., 2002; Gates et al., 2005). Gas emission may be measured by several methods as outlined in Phillips et al. (2000). Within the currently accepted practices, one considered to be among the most accurate is estimating emission rate as the product of ammonia concentration and ventilation exhaust airflow rate.

Broiler chickens are floor-raised on litter that starts as new bedding (sawdust, wood shavings, rice hulls, etc.) and becomes a mixture of decomposing manure and bedding as birds grow. New bedding is typically placed in the barn once per year and then used repeatedly, also known as *built-up* litter, over several flocks. After about a year, the accumulated built-up litter is removed from the barn and fresh bedding is added. Built-up litter is the major source of volatilizing ammonia and its management is a key factor affecting emission rate. A minority of USA broiler barns receive new bedding for each flock although this is common practice in other countries, particularly in Europe, Australia and Brazil.

Controlling litter moisture content and pH are the major management strategies for reducing ammonia volatilization. The production and volatilization of ammonia is inhibited by litter pH below 7 because pH directly affects the equilibrium between ammonium (NH_4^+) and ammonia (NH_3). However, control of litter pH over the life of the flock has proven to be a difficult task, in part because litter pH is not commonly measured, the effect of treatment is not long-lasting (typically only 10-14 days), and repeated treatments are impractical with birds in the barn. The acidifying compound, such as sodium bisulphate [$NaHSO_4$], is usually applied to the litter just prior to chick placement in the barn with an expectation of lowered ammonia volatilization during the critical brooding period (up to 14 d) when the birds are felt to be more susceptible to the health challenges of elevated ammonia levels (above 25 ppm). High temperatures during brooding (28-34°C) also enhance ammonia volatilization. Some research however, has failed to demonstrate a difference in ammonia emissions from litter treated with $NaHSO_4$ and untreated litter (Moore et al., 1996).

The objective of the study presented here was to investigate the influence of litter management strategies on ammonia emissions from broiler barns employing new bedding, acid-treated built-up litter, or untreated built-up litter. The information presented here utilizes nearly 400 barn-days of ammonia emissions data collected from one year of observations at 12 commercial broiler barns in two climate regions: four in Pennsylvania (PA) and eight in Kentucky (KY). It was considered appropriate to combine data on litter treatments for evaluation across seasons and farms for the following reasons. There was little difference in ammonia emissions generated within the two study climates, cold (PA) and mixed-humid (KY). The offsetting relationships of high ammonia concentration at low ventilation rates (cold weather) versus low ammonia concentration at high ventilation rates (hot weather) resulted in fairly consistent ammonia emission rates from flocks of same age birds over the seasons, but with slightly higher emission rate observed during hottest weather (Wheeler et al., 2006).

Ammonia Emission Rate Model

Ammonia emission rate (ER) for all data from the 12 broiler barns being discussed in this paper was published without differentiation among litter treatment in Wheeler et al. (2006). The relationship shows a general linear trend of increasing ER with bird age as more manure is deposited and accumulated in the production barns as the birds grow. The following general relationship expressed ER (±SE) for the 12 broiler barns on all litter (AL) types:

$$ER = 0.031(\pm 0.0011)*x \quad (1)$$

where ER = emission rate, g NH_3 bird^{-1} d^{-1}
x = flock age (d), if built-up litter
= 0, if new bedding and flock age < 7 d
= flock age – 6 (d), if new bedding and flock age ≥ 7 d

Methods

Environmental conditions in each of the twelve commercial broiler barns on four farms were monitored during at least thirteen, 48-hour periods over the course of one year. The monitoring periods provided data to determine ammonia emission from the broiler barns during different seasons with various age birds during at least five flock grow-out cycles. In order to economically obtain data from as many barns as possible over the year, the instrumentation was taken to one set of barns the first week and another set of barns the second week with thorough cleaning for bio-security in between.

Barns and Flocks

On each study farm the barns, representing current construction, were paired for repetition of conditions. Wheeler et al. (2006) provides more detailed description about the unique features of study barns and environmental control systems. The primary difference between the two cold-climate study locations was that Farm PA-A barns had concrete floors and new kiln-dried wood shavings each flock (new bedding always: NBA) while Farm PA-B had built-up litter on crushed shale floors. Farm PA-B's second study flock was on new wood shavings bedding after the annual litter cleanout (new bedding cleanout: NBC). For flocks with cold-weather start dates, Farm PA-B incorporated 0.24 kg/m^2 (50 lb/1000 ft^2) of either sodium bisulphate (PLT® , Jones-Hamilton, Walbridge, OH) or a granulated sulfuric acid product (Poultry Guard™, WYNCO Animal Health, Springdale, AR) in the brood section in both barns on the day before chick placement (treated litter: TL). Additional litter treatment was applied in the non-brood section of the barn, at the same application rate, the day birds were moved into that section. All mixed-humid climate barns were managed with built-up litter (BL) that started as sawdust bedding, with some barns employing an acid litter treatment (sodium bisulphate (PLT®) at 0.24 kg/m^2 to the litter of the brooding section). All acid applications were at manufacturer's recommended rate. Table 1 shows flocks and their litter management code. For the 396 days of data collection, 52, 48, 142 and 154 days were studied as NBA, NBC, TL and BL, respectively.

Bird numbers and weights over the entire growth cycle were needed for emission estimates. Bird placement number and weights for age were obtained from the integrator companies in KY (proprietary information). In PA bird weights were estimated from field data on birds of the same strain during a previous study (Wheeler et al., 1999) and bird number was actual daily house population. Indoor and outdoor temperature (T) and relative humidity (RH) were monitored (±0.4°C [±0.7°F] and ±3% RH; HOBO Pro Series, Onset Computer Corporation, Bourne, Mass.)

Table 1. Flock placement start dates for study year from late 2002 through 2003. NBA = new bedding always; NBC = new bedding cleanout; TL = acid treated litter; BL = built-up litter

	Cold Climate				Mixed-Humid Climate			
	Farm PA-A 2 Barns		Farm PA-B 2 Barns		Farm KY-A 4 Barns		Farm KY-B 4 Barns	
Flock	Start date	Litter code	Start date	Litter code	Start date	Litter code (No. barns)	Start date	Litter code (No. barns)
1			Jan	TL	Nov	TL (4)	Nov	TL (2); BL (2)
2	Feb	NBA	Mar	NBC	Jan	TL (4)	Feb	TL (2); BL (2)
3	Apr	NBA	May	BL	Mar	NBC (1); TL (3)	Apr	TL (2); BL (2)
4	Jun	NBA	Jun	BL	May	NBC (3); BL (1)	Jul	TL (2); BL (2)
5	Aug	NBA	Aug	BL	Jul	BL (4)	Sep	TL (2); BL (2)
6	Oct	NBA	Oct	TL	Sep	BL (4)		

Ammonia Concentration Instrumentation

Portable Monitoring Units (PMUs) were designed to monitor gas concentration and static pressure difference between interior and exterior conditions on one-minute intervals. Detailed information about the design and performance of the PMU was provided by Xin et al. (2002), Xin et al. (2003) and Gates et al. (2005). Briefly, the PMU was a tight-closing panel-box that held instrumentation for emissions data collection that was portable and cleanable for use in multiple barns. At least one PMU was wall-mounted in each broiler barn during a study period to monitor conditions of exhaust air and fresh outside air.

Instrumentation within the PMU included two identical gas monitors for redundant measurement of ammonia concentration (0-200 ppm; PAC III, Dräger Safety, Inc, Pittsburgh, Pa.) with plumbing and controls (pump, solenoid valve, flow meters for controlled flow) for cycling fresh, outside air and poultry barn air past the sensors. The electrochemical sensors were purged with fresh air (for 24 minutes in PA; 14 minutes in KY) to reduce sensor saturation from continuous ammonia exposure. Sensors were exposed to barn air for 6 minutes between fresh air purge cycles. An ammonia value for emission rate calculation was selected from the 6-minute interval of barn air to represent ammonia level in the barn over the 20 or 30 minute house-air-purge-air cycle, as described in Xin et al. (2003).

Air samples were drawn into the PMU through two lengths of polyvinyl-chloride 9 mm (3/8-inch) o.d. transparent flexible tubing. The barn air sample tube was 2-3 m long with air intake positioned in front of the monitored exhaust fan. The purge air line intake was positioned outside the poultry barn, at the eaves in between fresh air inlet boxes on the barn sidewall that did not have exhaust fans. Filters were used to exclude larger particulates and insects from clogging the air collection lines.

Fan Ventilation Rate

Ventilation rate (VR) was calculated using actual fan performance and run-time data then corrected to conditions of standard temperature and pressure. Each PMU monitored static pressure difference (0-125 Pa, 0-0.5 in.H_2O, Model 264, Setra Systems, Inc, Boxborough, Mass.) used in calculation of ventilation rate. Fan run-time was recorded using on/off motor loggers (HOBO on/off motor, Onset Computer Corporation, Bourne, Mass.) installed on electric cable "pigtails" between the electric supply receptacle and plug to each fan. These loggers provided time of state change with a resolution of 0.5 second. Data were analyzed into 20-minute (KY) or 30-minute (PA) periods to match ammonia data analysis interval.

The "actual" exhaust fan ventilation capacity was determined *in situ* with a traversing anemometer array, the Fan Assessment Numeration System (FANS) unit (Gates et al. 2005; Casey et al., 2002). The FANS consisted of five vane anemometers positioned on a bar that traversed the entire airflow entry area to each fan. The FANS was used to develop performance curves for each individual fan in each barn (11, 14 or 15 fans per house) over a range of six typical building static pressure differences (0 to 50 Pa, 0 to 0.18 in. H_2O). The FANS was positioned on the intake side of the fan of interest and sealed against air leaks. Additional detail of procedures in using FANS to evaluation fan air flow rate is found in Wheeler et al. (2006, 2002) and performance of fans as determined by these tests in Casey et al. (2008).

Building ventilation rate was determined by multiplying fan capacity of each individual fan in relation to operating static pressure by that fan's actual run-time during that data collection interval. All fans running during that 20- or 30-minute interval were summed for the total building ventilation rate. Each interval was summed over a 24-hour period. Reported ventilation data are the average rate in m^3/hr per 1000 birds for that 24-hour period.

Emission Rate Determination

The NH_3 emission rate was calculated as the average mass of NH_3 emitted from the broiler barns per bird in a unit time by multiplying building ventilation rate at interior temperature by exhaust air ammonia concentration. Wheeler et al. (2006) provides equation and detail of standard conditions used (273.15K and 101.325 Pa). Ammonia concentration of the exhaust air [NH_3] without subtraction of that from the intake was used in the calculation of emission rates for this study since the fresh air purge cycle contained ammonia below the threshold detection level of our electrochemical instrument.

All ammonia sensors were calibrated immediately prior to each study field trip and checked for calibration upon return from the field. NIST-certified calibration gases were used for two-point calibration. All sensors heads were replaced within the project in an attempt to maintain sensor integrity. Raw data from KY were shared with PA, and vice-versa, to check for errors and omissions in calculations.

Results and Discussion

Daily Emission Rate per Bird by Litter Management

Figures 1 and 2 show regression relationships of ER to bird age for new bedding and a subset of the treated litter and built-up litter flocks, respectively. The new bedding (NB) flocks in Figure 1 were further divided into those that started on new bedding always (NBA) and those that were managed with only one flock per year on new bedding after a cleanout (NBC). The high R^2 values (0.80 and 0.86) of these two relationships indicate that bird age explains a lot of the variability in ER during these flocks versus other factors such as ventilation rate, indoor air T or outside T. The value of each line's slope can allow comparisons among the litter management strategies. The five NBA flocks had a reduced slope (0.0240 ER/d) to the ER-age relationship versus that seen with the 10 NBC flocks (0.0352 ER/d). The intercept of the two relationships was similar at an equivalent of 6.1 and 6.2 days for NBA and NBC, respectively (intercept/slope = days). When all NB data are combined the slope of the relationship (0.0315 ER/d) is similar to the composite of all data (0.0308 ER/d in Eqn. 1), but the favorable intercept remains with about 6.5 days of virtually emission-free broiler production.

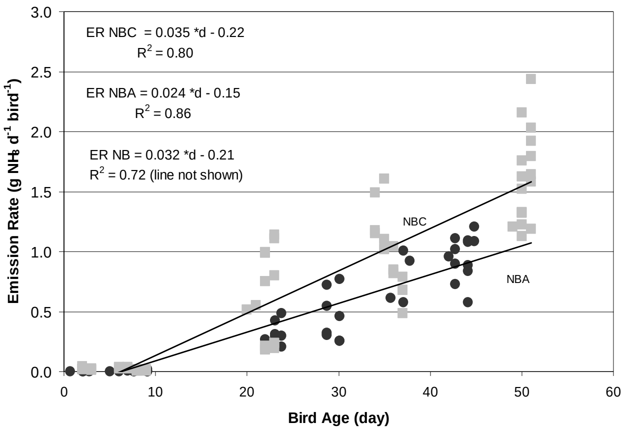

Figure 1. Ammonia emissions for new bedding (NB) flocks showing NB Always (NBA) with lower slope of 0.024 and NB Cleanout (NBC) with slope similar to all litter (AL; Eqn. 1) data, with both NB categories having 6 d of essentially no emission rate (ER). For combined NBA and NBC, equation ER NB is shown.

The treated litter (TL) flocks and the built-up litter (BL) flocks were analyzed separately (figures not included). There was a slightly reduced slope to the ER-age relationship with TL flocks (0.0295 ER/d) compared to the BL (0.0311 ER/d) and all flocks (AL): (0.0308 ER/d). Since litter treatments are applied before birds arrive and are only expected to function for a week or two, the latter part of each flock cycle should be similar for TL and BL flocks.

Table 2 provides a summary of the ER linear equation parameters along with ER estimates at a few bird ages. The TL flocks do have an advantage over BL flocks early in the cycle but this advantage narrows near the end of the flock cycle. A diminishing advantage as the flock ages was also seen for the NBC flocks. The only treatment that was consistently lower in ammonia emission over the flock cycle was NBA while BL was always the highest.

Table 2. Summary of ammonia emission rate (ER) linear equation parameters for the litter management strategies under study and an estimate of daily per bird emission at various bird ages.

				ER (g NH_3/bird d)				
Litter code	slope	intercept	R^2	day of age				
	ER/d	ER			7	20	42	60
NBA	0.0240	-0.152	0.87		0.02	0.33	0.86	1.29*
NBC	0.0352	-0.218	0.80		0.03	0.49	1.26	1.89
TL	0.0295	0.0121	0.66		0.22	0.60	1.25	1.78
BL	0.0311	0.0824	0.60		0.30	0.70	1.39	1.95
AL	0.0308	-0.0321	0.64		0.18	0.58	1.26	1.82

NBA = new bedding always; NBC = new bedding after cleanout; TL = treated litter; BL = built-up litter; AL = all litter in this study. *extrapolated beyond 45-day data collection timeframe.

Emissions from NBA and NBC managed flocks were expected to be similar and the observed differences were likely caused by conditions not characterized by bird age and barn environment. The NBC flocks tended to be on longer flock cycles, which increased the overall ER-bird age regression slope. This does not fully explain the differences since even at similar ages, the NBC flocks tended to have higher ammonia ER than NBA flocks (Figure 1). Another reason for elevated ammonia emissions for NBC flocks include the absorbed nitrogen in the packed soil within the broiler barn from previous BL (or TL) flocks (Lomax et al., 1997; Wheeler et al., 1999) although this effect should have also been observed, but was not, in the first week of NBC flocks. The NBA flocks in this study were housed on concrete floors that do not readily absorb nitrogen products (Lomax et al., 1997) and are more easily scraped for thorough removal of the spent litter and manure material between flocks.

Treated and Built-up Litter Comparison on One Farm

Farm KY-B was studied with two barns using litter treatment and two identical barns with untreated, built-up litter for a side-by-side comparison of results under field conditions. Figure 2 presents ER versus age relationship for the BL and TL barns. All four barns were cleaned once at the same time during the study year and those new bedding data are excluded from Figure 2 (but included in Figure 1 as part of NBC flocks).

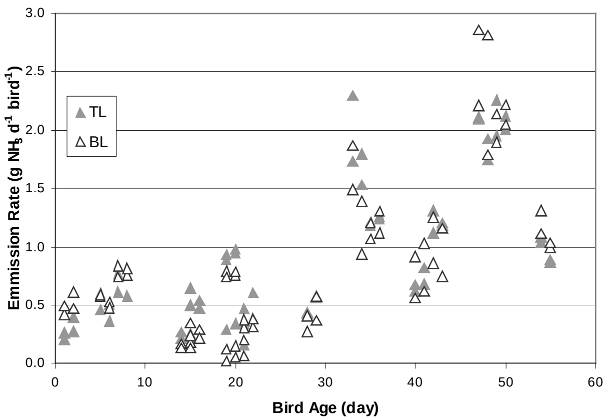

Figure 2. Sub-experiment of treated (TL) versus built-up (BL) litter in four barns (2 TL; 2 BL) on same farm for direct comparison. (New bedding (NBC) flocks removed from data set.)

Emissions from TL and BL barns were similar but the temporal pattern of emissions varied. At bird age less than 10 days the TL flocks produced lower ER compared to BL flocks. After the first two weeks, this pattern reversed with TL barns almost always having greater emissions than untreated barns (BL) for the same study day (bird age). After the third week, the two types of manure management resulted in similar ERs. This provides evidence that ammonia held in the litter by the litter treatment at the beginning of the flock was available for release later in the cycle.

Emissions Comparisons

Average ER over a flock cycle increases when birds are raised to greater weights, on built-up litter, and/or at high stocking densities. Ammonia ER of USA broilers raised under typical commercial conditions to 42 or 49 days on built-up litter, using a bird age of one-half final market age, were fairly consistent among studies ranging from 0.63 (Lacey, et al., 2003) and 0.62 g NH_3/(bird d) (Wheeler et al., 2006) to 0.92 g NH_3/(bird d) (Burns, et al., 2003) and 1.18 g NH_3/(bird d) (Seifert, et al., 2004). Burns et al., (2007) reported a mean ER of 0.62 g NH_3/(bird d) during continuous measurement of 9-flocks of 42-day market broilers on built-up litter. Broiler stocking densities for a finished bird weight of about 2.2 to 2.4 kg in these studies ranged from 14.7 to 20.0 birds/m^2, with higher ER at increased stocking density. Increasing bird density with its associated increased uric acid (precursor to ammonia) excretion per floor area has the potential for increased ammonia emissions. Similarly, European birds, typically raised on new bedding each flock to smaller market weights, result in reduced ER (Wheeler et al., 2006). Broilers raised on new bedding each flock had a reduced ER of about 0.47 g NH_3/(bird d) (Wheeler et al., 2006) using Equation 1. A mean ER from three flocks of NBC was reported as 0.49 g NH_3/(bird d) by Burns et al. (2007). Our study reported here demonstrated 0.35 or 0.52 g NH_3/(bird d) at 21 d bird age using an equation specifically for either NBA or NBC flocks, respectively.

Conclusions

The litter management strategy that was consistently lowest in ammonia emission, expressed in terms of g NH_3/(bird d) for birds at 21 days of age (median age for 42 day flock cycle) was new bedding every flock at 0.35 g NH_3/(bird d), followed by flocks raised on the annual cleanout with new bedding at 0.52 g NH_3/(bird d). Built-up litter had the highest ammonia emission of 0.73 g NH_3/(bird d), which is more than double the new bedding flocks. Acid-treated litter at 0.63 g NH_3/(bird d) was 14% lower than built-up litter emission. Ammonia emissions from treated litter and built-up litter barns were similar but the temporal pattern of emissions provided evidence that ammonia held in the litter by the acid-treatment during the first 10 to 14 days of the flock was released during the subsequent two-week growth period.

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